take at some future time. Of these three types the first is the most rare, the second the most familiar and the third the most popular. Professor Münsterberg's book belongs to the third type, and its popularity is indicated by the fact that during the month of April it was reported among the six best selling non-fiction books in the largest cities of Maryland, Massachusetts, Illinois, Michigan, Florida, Minnesota and New York, along with "The New Freedom," "The Promised Land," the Montessori books, "Zone Policeman 88" and "Auction Bridge of To-day."

The book contemplates the ultimate development of a science of "psychotechnics" which shall handle the problems of industry and economics by the application of the technique of experimental psychology. The various chapters give a series of interestingly presented illustrations of the psychotechnic point of view, the selection of examples being confined to those fields of industry which have not yet been systematically explored by applied psychology.

Tests for vocational guidance; methods of scientific management; elimination of unfit individuals from railway, ship and telephone service; economy of movement; fatigue and monotony; types of attention; the influence of weather, drugs, entertainment, rhythm, and other physical and social factors; the effectiveness of advertisements; illegal imitation; buying and selling;—all these topics, and similar ones, are discussed from the point of view of the three problems—"How to find the best possible man, how to produce the best possible work and how to secure the best possible results." Preliminary experiments are described and the work of other workers briefly summarized. The author frequently remarks that most of the experiments represent only the beginnings of investigations, which, it is hoped, will in time yield significant and useful results.

Of particular interest is the author's recognition of the importance of interests, inclinations and emotional attitudes, and of the desirability of devising tests which will measure an individual's ability to grasp a general situation. Tests of this sort will doubtless prove to be of much greater diagnostic value than the simple sensori-motor measurements. More complete data are promised in forthcoming reports of detailed investigations now being carried on in the author's laboratory. These reports will presumably belong to the rare first variety of monographs, and will be looked forward to with interest by professional psychologists to whom the present book constitutes not so much a contribution as a challenge to fulfil the prophecies of a fellow worker. Perhaps the most immediate value of the book comes from the ingenuity with which its problems are conceived and the preliminary tests devised. Professor Münsterberg's hopefulness for the future possibilities of "psychotechnics" does not keep him from placing a commendably conservative value on the actual results and correlations of his own preliminary studies.

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SPECIAL ARTICLES

THE EMISSION OF ELECTRONS FROM TUNGSTEN AT HIGH TEMPERATURES: AN EXPERIMENTAL PROOF THAT THE ELECTRIC CURRENT IN METALS IS CARRIED BY ELECTRONS

THAT the carriers of the negative thermionic current from incandescent solids are negative electrons was first established by J. J. Thomson.[1] In 1901[2] the writer developed the view that this emission of negative electrons occurred by virtue of the kinetic energy of thermal agitation of some of the electrons in the solid exceeding the work which was necessary to overcome the forces which tend to retain them in the body and which prevent them from escaping at lower temperatures. This conception has proved a very fruitful one and its consequences have been verified in a number of ways. It has provided a quantitative explanation of the variation of the number of electrons emitted with the temperature of the body. It led to the prediction of a cooling

[1] *Phil. Mag.*, Vol. 48, p. 547 (1899).

[2] *Camb. Phil. Proc.*, Vol. 11, p. 286 (1901); *Phil. Trans., A*, Vol. 201, p. 497 (1903).

effect when electrons are emitted by a conductor and a corresponding heating effect when they are absorbed. Both these effects[3] have since been detected experimentally and found to be of the expected magnitude, within the limits of experimental error. The magnitude and distribution of energy of the emitted electrons has been found by experiment to be that given by Maxwell's law,[4] in accordance with the requirements of the theory. Finally, the same general train of ideas has led to valuable applications in the direction of the theory of metallic conductors,[5] contact potential[6] and photoelectric action.[7]

It has long been known that ions are emitted in a number of cases in which solids react chemically with gases. The recent experiments of Haber and Just[8] indicate that the alkali metals liberate electrons when they are attacked by certain gases. It seems likely, from various considerations,[9] that effects of this nature would account for most of the emission from heated sodium which was measured by the writer.[10] In consequence of this conclusion, together with the results of a number of experiments which are at first sight in conflict with the theory referred to at the beginning of this paper,[11] the view appears to have become rather prevalent that the emission of electrons from hot bodies is invariably a secondary effect arising in some way from traces of chemical action. That this view is a mistaken one is, I think, conclusively shown by the following experiments which I have made with tungsten filaments.

The tests to be described were made with experimental tungsten lamps carrying a vertical filament of ductile tungsten which passed axially down a concentric cylindrical electrode of copper gauze or foil. The tungsten filaments were welded electrically in a hydrogen atmosphere to stout metal leads. These in turn were silver soldered to platinum wires sealed into the glass container. The lead to the copper electrode was sealed into the glass in the same way. The lamps were exhausted with a Gaede pump for several hours, during which time they were maintained at a temperature of 550–570° C. by means of a vacuum furnace. The exhaustion was then completed by means of liquid air and charcoal, the tungsten filament meanwhile being glowed out by means of an electric current at over 2200° C. Most of the tests were made after the furnace had been opened up and the walls of the lamps allowed to cool off. They were always considerably above the temperature of the room on account of the heat radiated by the glowing filament.

The processes described are extremely well adapted for getting rid of the absorbed gases and volatile impurities which form such a persistent source of difficulties in experiments of this character. Unless some such treatment is resorted to, the metal electrodes and glass walls of these tubes continue to give off relatively large amounts of gas under the influence of the heat radiated from the filaments and it has always been possible that this evolution of gas might have played an important part in the electronic emission. The mode of treatment used, for which I am largely indebted to the experience and suggestions of Dr. Irving Langmuir, of the General Electric Company's Research Laboratory at Schenectady, N. Y., seems very superior to anything in this direction which has previously been published.

Tests have been carried out covering the alternative hypotheses as to the possible mode

[3] Richardson and Cooke, *Phil. Mag.*, Vol. 20, p. 173 (1910), Vol. 21, p. 404 (1911); Cooke and Richardson, *Phil. Mag.*, Vol. 25, p. 624 (1913).

[4] Richardson and Brown, *Phil. Mag.*, Vol. 16, p. 353 (1908); Richardson, *Phil. Mag.*, Vol. 16, p. 890 (1908); Vol. 18, p. 681 (1909).

[5] Richardson, *Phil. Mag.*, Vol. 23, p. 594 (1912); Vol. 24, p. 737 (1912).

[6] Richardson, *Phil. Mag.*, Vol. 23, p. 263 (1912).

[7] Richardson, *Phil. Mag.*, Vol. 24, p. 570 (1912); Richardson and Compton, *Phil. Mag.*, Vol. 24, p. 575 (1912).

[8] *Ann. der Phys.*, Vol. 30, p. 411 (1909); Vol. 36, p. 308 (1911).

[9] Cf. Fredenhagen, *Verh. der Deutsch. Physik. Ges.*, 14 Jahrg., p. 384 (1912); Richardson, *Phil. Mag.*, Vol. 24, p. 737 (1912).

[10] *Phil. Trans., A*, Vol. 201, p. 497 (1903).

[11] Cf. Pring and Parker, *Phil. Mag.*, Vol. 23, p. 192 (1912).

of origin of the electronic emission which are enumerated below:

1. The emission is due to the evolution of gas by the filaments.

The lamp and McLeod gauge were cut off from the rest of the apparatus by means of a mercury trap, the volume being then approximately 600 c.c. A filament 4 cm. long giving a thermionic current of .064 amp. was found to increase the pressure from zero to $< 1 \times 10^{-6}$ mm. in five minutes. The number of molecules N_1 of gas given off is therefore $< 2.13 \times 10^{13}$. The number of electrons given is $N_2 = 1.2 \times 10^{20}$. The number of electrons emitted for each molecule of gas evolved is thus $N_2/N_1 > 5.64 \times 10^6$.

In the above experiment a liquid air trap was interposed to keep the mercury vapor off the filament. In another experiment with a filament 8 cm. long this was not the case and with a current of .050 amp. the pressure rose in thirty minutes to a value which was too small to measure, but which was estimated as less than 10^{-7} mm. The corresponding value of N_2/N_1 is 2.6×10^8. In this case the current was unaffected when the mercury vapor was subsequently cut off by liquid air (a change of 0.4 per cent. would have been detected).

The magnitude of the above numbers effectually disposes of the idea that the emission has anything to do with the evolution of gas.

2. The emission is caused by chemical action or some other cause depending on impacts between the gas molecules and the filaments.

In a tube with a filament 1.4 cm. in length and having 1.65×10^{-2} cm² superficial area the pressure rose to $< 2 \times 10^{-6}$ mm. in 5 minutes with an emission of .050 amp. If the gas is assumed to be hydrogen, which makes most impacts, using a liberally high estimate of the temperature of the copper electrode which determines the temperature of the gas, I find that the maximum number N^1 of molecules impinging per second during this interval would be $< 7.0 \times 10^{13}$. The number of electrons emitted per second would be $N_2 = 3.13 \times 10^{17}$. The ratio N_2/N^1 is thus $> 4.47 \times 10^3$. If the putative hydrogen atoms simply turned into a cloud of electrons whose total mass was equal to that of the hydrogen the value of N_2/N^1 would be only 3.68×10^3. The data already referred to for the tube with the filament 8 cm. long give an even larger ratio for N_2/N^1, namely, 1.57×10^4. Moreover, in some of our experiments the changes in gas pressure were much larger than those recorded above, but they were never accompanied by any change in the electronic emission: also the admission of mercury vapor at its pressure (about 0.001 mm.) at room temperature produces no appreciable change in the emission. Thus there is no room for the idea that the emission of electrons has anything to do with the impact of gas molecules under the conditions of these experiments.

3. The emission is a result of some process involving consumption of the tungsten.

To test this question some of the lamps were sealed off after being exhausted in the manner described. The filaments were then heated so as to give a constant thermionic current which was allowed to flow for long intervals of time. In this way the total quantity of negative electricity emitted by the filament was determined. The wire was placed in one arm of a Wheatstone's bridge so that the resistance could be recorded simultaneously. The cold resistance was also checked up from time to time.

At these high temperatures the resistance of the filaments increases slowly but continuously. This increase is believed to be due to evaporation of the tungsten. It was found to be proportional to the time of heating when the thermionic current was kept constant, in the case of any particular filament. In the case of one filament which gave 0.05 amp. for 12 hours the increase in the resistance of the hot filament was 9 per cent. The accompanying proportionate increase in the cold resistance was slightly lower, namely, 7 per cent. The latter may probably be taken as a fair measure of the amount of tungsten lost by the filament. The increase in resistance of the hot filament, which is less favorable for our case, will be considered instead

in the following experiment for which the other data are lacking.

A filament 3 cm. long gave 0.099 amp. electronic emission continuously for 2.5 hours. The resistance when hot rose from 4,773 to 4,787 in arbitrary units. The number of atoms of tungsten lost by the filament in this time was $= 5.66 \times 10^{15}$, whilst the number of electrons emitted $= 5.57 \times 10^{21}$. The number of electrons emitted per atom of tungsten lost was 9.84×10^{5}. The mass of the electrons emitted in this experiment was thus very close to *three times* the mass of the tungsten lost by the filament.

This tube gave 0.1 amp. electronic emission on the average for 6 hours altogether. By that time the mass of the electrons emitted was approximately 2 per cent. of the mass of the tungsten filament. The tube came to an end owing to an accident: the filament gradually became deformed until it touched the copper electrode and broke. The hardness of the tube was then tested with an induction coil and the equivalent spark gap was found to be 3.3 cm. The discharge through the tube gave a bright green fluorescence on the glass around the negative wire, but there was no indication of a glow or the faint purple haze which is obtained when traces of gas are present in tubes of this kind. There is thus no appreciable accumulation of gas even when the filaments are allowed to emit a large thermionic current continuously for a long time.

Another tube with a wire 2.7 cm. long, giving 0.050 amp., lost 1.19×10^{17} atoms of tungsten in 12 hours as measured by the change in the cold resistance. The number of electrons emitted for each atom of tungsten lost was thus 1.13×10^{5} and the mass of the emitted electrons about one third of the mass of the tungsten lost. This tube ran altogether for about 23 hours, giving various currents, and finally gave out, owing to the local loss of material near one end, caused by the sputtering or evaporation. Local over-heating is very apt to occur in these experiments as the thermionic leakage causes the heating current in the wire to be bigger at one end than the other. The mass of all the electrons emitted by this filament was equal to 4 per cent. of its total mass. Under a low-power microscope the filament did not appear to be much changed except in the region where it had burnt out, where it was much thinner than elsewhere.

There is no known reason for believing that the loss of tungsten is due to anything more profound than evaporation. But, in any event, the fact that the mass of the emitted electrons can, under favorable circumstances, exceed that of the tungsten loss proves that the loss of tungsten is not the cause of the electronic emission.

4. The only remaining process of a similar nature to those already considered which has not been discussed is the bare possibility that the emission is due to the interaction of the tungsten with some unknown condensable vapor which does not affect the McLeod gauge. This possibility is cut out by the fact that the thermionic emission is not affected when the liquid air and charcoal is cut off and the vapors allowed to accumulate in the tube, and by the fact that very considerable changes in the amount and nature of the gases present (as by the admission of mercury vapor) have no effect on the emission.

Taken together these experiments prove that the emission of electrons does not arise from any interaction between the hot filament and surrounding gases or vapors nor from any process involving consumption of the material of the filament. It thus follows that the emission of electrons from hot tungsten, which there is no reason for not regarding as exhibiting this phenomenon in a typical form, is not a chemical but a physical process. This conclusion does not exclude the possibility that, under other circumstances, electrons may be emitted from metals under the influence of various chemical reagents, a phenomenon which would be expected to exhibit the same law of dependence upon temperature; but it does involve a denial of the thesis that this emission is invariably caused by processes involving changes of material composition.

The experiments also show that the elec-

trons are not created either out of the tungsten or out of the surrounding gas. It follows that they flow into the tungsten from outside points of the circuit. The experiments therefore furnish a direct experimental proof of the electron theory of conduction in metals.

I wish to express my appreciation of the assistance I have received from Mr. K. K. Smith, instructor in the laboratory, in the preparation of the tubes and in carrying out some of the measurements. Mr. Smith and I are engaged in a more detailed quantitative study of the emission of electrons from tungsten, the results of which we hope shortly to publish. I also wish to thank Dr. W. R. Whitney and Dr. I. Langmuir, of the General Electric Company, both for supplying the specimens of ductile tungsten used and also for giving me the benefit of their invaluable experience.

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MENDELIAN INHERITANCE OF EPIDERMAL CHARACTERS IN THE FRUIT OF CUCUMIS SATIVUS

THE fruits of the White Spine cucumber (*Cucumis sativus*) possess numerous white epidermal spines or trichomes which roughen the skin very markedly; while those of the Richard's Invincible, an English forcing type (var. *Anglica*), possess but few, small, indistinct, early-deciduous and black spines that scarcely roughen the skin. By crossing these varieties, the White Spine having been used as the maternal parent, there was obtained a type of fruit apparently intermediate in size and in number and prominence of the spines, with the exception that all the spines were black like the paternal parent. In the F_2 generation, of the twenty plants grown fifteen bore black spines and five white spines; six possessed smooth skins with indistinct spines like the Richard's Invincible and the remainder skins with various degrees of roughness—a few even surpassing the White Spine in the number of spines. No correlation of color of spines and roughness was noted—smooth-skinned progeny possessing white as well as black spines.

The inheritance of the color of the spines apparently follows the simple Mendelian segregation, although the number of progeny is too small for a very exact interpretation; the small number of smooth-skinned types also indicates this character as a recessive one, especially as the F_1 fruits show no evidence of this character. Practically, these data are of little value unless they indicate that by crossing back one of these smooth-skinned, white-spined fruits with an English variety, it would be possible to obtain a new white-spined variety, differing in appearance but slightly from var. *Anglica;* theoretically, it adds a little more evidence to the support of Mendel's universal law.

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POWDERY SCAB OF POTATOES IN THE UNITED STATES

IN a recent number of *Phytopathology* Professor H. T. Güssow, of Canada, Dominion Botanist, reported for the first time in America the occurrence of the well-known European "powdery" or "corky" scab of potatoes.[1] The specimens upon which he based this report were received first from Quebec, where the disease appeared to be well established in some counties. It was also recorded in isolated cases in widely separated regions of Canada, namely, Cape Breton, Nova Scotia, New Brunswick, Ontario and Alberta. These facts led Professor Güssow to suggest that probably the disease occurs in the United States.

In connection with certain studies now being carried on in the writer's laboratory upon the general subject of potato scab, requests for specimens of scabby tubers have been sent to many individuals representing widely separated localities in the state of Maine and also

[1] Güssow, H. T., "Powdery Scab of Potatoes, *Spongospora subterranea* (Wallr.) Johns.," *Phytopathology,* 3: 18–19, 1913.